The spatial impact of building in concrete versus building in wood

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1. Introduction

To be able to build with cement concrete coarse sand, gravel and limestone must be extracted. There is a lot of protest against quarrying due to the fact that a lot of space is required for excavating. Many areas have been transformed into water areas, due to the fact that we lack e.g. hard rock outcrops that can be crushed to aggregates for concrete.

Wood is a renewable raw material and therefore, from a sustainability point of view, to replace cement concrete by wood seems to stand an excellent chance. The Dutch climate is excellent for growing trees. That is why a policy has been launched to use more wood in the building industry (see Milieuberaad Bouw - Environmental Council for the Construction Industry - , 1995). In the Structural Outline Plan on Surface Minerals, where the goverment's policy on raw material provision has been put down, it is also stated that application of renewable raw materials as a replacement for surface minerals should be encouraged (see Ministerie van Verkeer en Waterstaat - Ministry of Transport and Public Works -, 1996, p. 6).

This article pursues a recent study on the spatial implications of building with cement concrete versus building with wood. It is an exploratory research carried out at the Faculty of Spatial Sciences of the University of Groningen (see Van Barneveld, et al, 1997). The mentioned study provides a preview for at least the coming one hundred years.

Next section looks into the space required for the extraction of coarse sand and gravel. In section three attention is paid to the policy concerning the provision of aggregates in The Netherlands. In section four the state of affairs regarding an 'Environmental-Index' for building with wood and building with concrete is discussed. In section five replacement of concrete with wood is further specified. The study involves a sectoral investigation in how far wood can be a substitute for cement concrete in the building industry. This results in maximum replacement percentages and various substitution factors for the different sectors in the construction industry. In section six the required space for the extraction of coarse sand and gravel is compared with the space needed for growing wood. In section seven the required spatial use for building with concrete and with wood is looked into again in the form of concluding observations.

2. Excavating for cement concrete.

Since 1990 the Dutch building industry requires about 14.5 million m^3 cement concrete annually. Approximately 8 million m^3 of it is used in the form of ready mix concrete and the other 6.5 million m^3 is used in the concrete goods industry (see ENCI/VNC). The ingredients for cement concrete are coarse sand, gravel, limestone (for cement) and water. On average 13 million tonnes of gravel and 13 million tonnes of sand is processed in the above quantities. Note that the figures mentioned are averages. Depending on its weight the quantities of gravel needed for ready mix concrete are considerably higher than those used in concrete goods.

Depending on the thickness of the gravel layers about 100 to 225 thousand tonnes of gravel per ha can be quarried in The Netherlands and its neighbouring countries. Assuming that gravel is used for the production of cement concrete, it would mean that annuallly 130 to 58 ha respectively must be excavated. As for the quarrying of sand in areas along rivers a yield of 150 to 250 thousand tonnes per ha can be taken into account. Regarding the application in cement concrete, this would mean an annual quarrying of 86 to 52 ha respectively. For making cement concrete a total of 215 ha (130 + 86) to 110 ha (58 + 52) will have to be excavated if the raw materials are extracted from areas along rivers. As for the quarrying of limestone for cement far fewer ha need to be excavated. In this article, however, this has not been taken into account. On average about 4.4 million tonnes of cement is used in the quantities of cement concrete mentioned above.

3. Policy on surface minerals

The main objective concerning the provision of surface minerals as put down in the Dutch Structural Outline Plan on Surface Minerals reads as follows:

"The State policy with respect to the provision of raw materials for the building industry aims to meet the demands of private individuals, companies and government in a socially responsible way. This policy has four objectives:

1) to encourage the use of raw materials in a most economical way.
2) to encourage the use of as many secondary materials as possible in a responsible way.
3) to promote the use of more renewable raw materials.
4) to care for a timely availabality of a sufficient supply of Dutch surface minerals in the total provision of raw materials for the building industry".

For the application of concrete cement one should think of a more efficient way of building by applying high-tension concrete, creating hollow spaces in construction components, etc.. In the mean time some experience has been gained in this field (see Keijts, 1996). In the long run the use of raw materials could go down by some 20 % or 30%. Lengthening the economic life of a construction, a more flexible use and sectional building are also possibilities to reduce the use of coarse sand and gravel. So far little experience has been gained with this. This requires a very high organizational structure. In the long term, however, this way of building could prove very profitable.

The efforts to apply secondary materials has meanwhile been set in motion. The Building Materials Implementation Plan aims at recycling 90% of the building and demolition waste. In 1993 already 66% was recycled.

With respect to the expansion of the application of renewable raw materials the first steps have also been made. Wood is as far as this is concerned the raw material that stands the best chance. Meanwhile an action plan has been drawn up. This should lead to a 20% increase in the consumption of wood in the construction industry in the year 2000 compared to 1990 (see Milieuberaad Bouw, 1995). In 1990 2,750,000 m^3 of wood was processed in the building industry (see Milieuberaad Bouw, 1995, p. 10). An increase of 20% corresponds with 550,000 m^3 of wood. Due to this 'only' 1,100,000 m^3 cement concrete less can be used if this wood is used for the replacement of concrete [1]. The conversion factors will be dealt with in section five.

In future gravel quarrying will be cut back completely, anyway that is how it has been formulated in the Dutch Structural Outline Plan on Surface Minerals of 1996. Gravel quarrying will only be allowed in the province of Limburg, just to meet its own demand. In this case a 'sufficient contribution' means very little. Consequently an estimated 20 million tonnes of gravel must be imported annually, 13 million tonnes of which is required for the production of cement concrete. With regard to the extraction of (coarse) sand no restrictions have been imposed yet. The annual requirement is about 20 millions tonnes. The Netherlands imports approximately 9 million tonnes and also exports 9 million tonnes of (coarse) sand annually.

The application of other comparable materials like crushed stone instead of gravel as raw material for cement concrete is in fact removing the (environmental) problem. For the extraction of crushed stone the spatial effects are, for that matter, completely different. For the removal of a piece of rock of several tens of meters high the spatial implications are totally different from the implications that go with the extraction of gravel, leaving lakes in the end.

4. Environmental measures

Very often surface minerals are not considered renewable raw materials. In general, however, this is not correct. Certainly sand and clay are still transported by our large European rivers and they are still deposited. The pace of sedimentation however, is much too slow compared to the speed of excavating. Besides, many workings haven't got a direct access to a river. As for clay in river forelands the situation is more favourable. Where a layer of clay has been extracted, a new layer can be deposited, so that after several years a new layer of clay can be extracted. This doesn't go for clay in polders. By using renewable raw materials other raw materials will be spared. This is in principle a lasting way of using raw materials.

Renewable materials can be harvested; they regenerate again and again. A perfect example is wood. At first sight it seems logical to change from building in concrete into building in wood as much as possible. The question, however, is whether wood is actually more sustainable than concrete. Meanwhile, various methods have been developed to establish the degree of burdening the environment with materials or products. In 1995 agreements were made within the Environmental Council for the Construction Industry upon a system to establish how products affect the environment. The Centre of Evironmental Sciences, Leiden, developed a method to standardize these effects, called the Environmentally Oriented Life Cycle Assessment of Products (LCA). The LCA covers the complete life cycle or, part of it. The LCA distinguishes five 'measures': exhaustive use of raw materials, energy, emissions, waste and nuisance. Differently applicable environmental effects can be distinguished per measure. Finally, the scores must be weighed in order to come to one 'Environmental Profile' or 'Index'. The method as described above fits in well with the ISO Standard 14040, series Environmental Management, Life Cycle Assessment which is in the making (see Keijts, B., 1997). What the users need is one figure. Unfortunately it has not come to that yet. The Ministry of Housing, Spatial Planning and the Environment for example, is working on a method to come to one 'Environmental Index' as good as possible. The present environmental measures raise much discussion. In the mean time efforts have been made for a number of products to show the effect on the environment (see Van Barneveld, et al, 1997, p. 24). In 1996, a method has been developed to quantitatively determine the impact of one type of house on the environment (see Stichting Bouwresearch, 1996). They however, did not consider the effects of location-specific factors within their model. Also, they assume that limestone and sand are not scarce resources and therefore, ommitted these resources from the exhaustive use of raw materials in the LCA index (see Stichting Bouwresearch, 1996, p. 49, 52). At the time of writing this article, there were no conclusive results for a case of whether the house was built with either concrete or wood. In view of the complexity it doesn't seem likely that a standard will be available in the near future. Besides there is not one environmental measure for cement concrete or wood. In principle each concrete construction or wood construction must be looked at individually. Therefore it is impossible as yet to give an answer to the question whether building with wood is more durable than building with concrete. In the following sections one of the many environmental effects that play a part in the LCA will be singled out, namely the use of space. In these sections the use of space needed for extracting sand and gravel for cement concrete is compared with the space that will be needed if wood is substituted for cement concrete.

5. Wood as a substitute for concrete.

Practice in The Netherlands and other countries has teached us for hundreds of years that all kinds of building constructions can be done in wood very well. This goes for houses, offices, warehouses, bridges, etc.. The reason that relatively little wood is used in the building industry in The Netherlands is the present tradition of using concrete in architecture. Besides, wood has still the image that it must be maintained well and that the cost of maintenance is relatively high. By making a better detailed plan for the construction components and the use of less harmful impregnating agents wood constructions will need less maintenance. If wood is not exposed to all weathers and/or moist soil it will not be affected. Currently wood that is exposed to all weathers must still be impregnated and maintained. In the future it is very likely that environment-friendlier methods will be used to prevent wood from rotting. Very promising indeed is the so-called Plato-process (PLATO = providing lasting advanced timber option). With this registered Plato-process softwood such as pinewood and poplar will become rot-free hard-wearing timber without the use of environmentally harmful chemicals (see Biersma, 1997).

Nowadays most constructions can be designed in wood by laminating and finger joints, improved detailed planning and joint techniques and prefab-components. In section four it has been emphasized that LCA-systematics are still in the making and therefore it is not possible in general to pronounce upon whether wood is better than concrete. Impregnating and maintaining wood are part of the environmental effects within the five environmental standards of the LCA method and should be judged in coherence with them.

So as to be able to make a comparison between wood and concrete in Table 1, column (b), the use of concrete for each sector of the building industry has been calculated first. The quantities are based on charts of the cement industry itself and on CBS-production charts regarding the concrete goods industry and the concrete mortar industry (see Van Barneveld, et al, 1997, p. 35).

There are various methods for building houses with wood such as massive timber and timber-frame building. In The Netherlands only 5% or 6% of the newly-built houses are designed in timber-frame building (see Stam, B, 1997). This is a very low percentage compared to countries like Sweden and the USA, where respectively 90% of the terraced houses and 90% of the low-rise buildings are done in timber-frame building (see Zweeds-Finse houtinformatie - Swedish-Finnish information on wood -, 1996). Wood as a building material has its restrictions. Buildings higher than four floors are difficult to build in wood due to the stiffness of the construction as a whole. That is why approximately 13% of the houses cannot be built in wood (see CBS, 1994). This means that 87% of the houses can be built in wood (see Table 1, column (d)). In the earlier mentioned survey the quantities of concrete and wood required for a standard newly-built house were compared had this house been built in concrete or timber respectively. In a standard house about 48.5 m^3 of concrete is used whereas for a timber-framed house about 19.5 m^3 wood is needed (see Van Barneveld, 1997, p. 37). Constructions in concrete are mostly more solid than constructions in wood. Wooden walls and floors could consist of styles covered with board. Therefore the volume required for building in wood is less than the volume required for building in concrete. The substitution factor for houses is about 48.5/19.5 = 2.5 (see Table 1, column (e)).

Building sector (a)	Consumption of concrete in m^3 /year (b)	Consumption of concrete per sector in % (c)	Maximum replacements percentages (d)	Substitution factor concrete/wood (e)
- Housebuilding	4,870,000	34	87	2.5
- Building factories, public utilities, etc.	5,860,000	40	73	2.4
- Civil Engineering-1	550,000	04	50	1.5
- Civil Engineering-2	3,220,000	22	00	0.0
Total	14,500,000	100	x	x
Weighted mean	x	x	61	1.9

Civil Engineering-1 = Structural works, facing and bank protection. Source: Van Barneveld, e.a. 1997
Civil Engineering-2 = Roadbuilding, tubes, etc.

Table 1. *The absolute and relative concrete consumption per sector in the building industry, the maximum replacement percentage and substitution factor concrete/wood*

For building factories, public utilities, etc. more or less the same approach has been pursued to dertermine the substitution factor concrete/wood. A distinction has been made for halls and sheds, offices, a combination of industrial buildings including an office, sheds and stables, schools and other buildings. The total quantity of concrete has been devided up in catagories according to floor area. Three possibilities have been looked into : a) no replacement possible, b) only replacement of the load bearing parts, c) replacement of every concrete element by wood. The calculations show that 73% of the concrete could be replaced by wood (see Table 1, column (d)). The substitution factor appeared to be 2.4, see Table 1, column (e), (see van Barneveld, et al, 1997, p. 42).

In civil engineering about 26% of the total quantity of concrete is used. Twenty two percent of this quantity is used in road construction, tubes and accessories, see Table 1, column (c). These construction parts can hardly be replaced by wood, see Table 1, Civil Engineering-2, columns (d) and (e). The remaining 4% of the concrete in the Civil Engineering-sector is used in structural works, facing and bank protection (Civil Engineering-1). From the early days, wood has always been used in this sector. Since 1995 only hard wood from sustainably managed tropical rainforests is allowed to be imported in The Netherlands. As a consequence the use of wood in this sector has somewhat been under pressure. It is estimated that 'just' 100,000 m^3 is used in the whole hydraulics sector. Most bridges in The Netherlands have small spans which are suitable for designing in wood. Recently two wooden cable bridges for pedestrians and cyclists were built with a width of 3.5 metres, a span of 50 metres, and two spans of 45 metres (see Meyer, 1997). In the first example mentioned the customer did not choose for designs in steel and concrete on the basis of cost considerations. In Table 1, column (d) it is assumed that 50% of these works could be replaced by wood. The substitution factor concrete/wood is estimated 1.5.

6. The use of space

With the aid of the substitution factors concrete/wood, calculated in the previous section, one could calculate in a simple way how many cubic metres of wood could possibly replace the total quantity of 14,500,000 m^3 of concrete mentioned in Table 1. First of all the weighted average maximum replacement percentage has been calculated in Table 1. The percentages of concrete per sector have been used here as weighing factor. The average replacement percentage appeared to be 61% (see Table 1). The weighted average substitution factor of 1.9 has been calculated in the same way, see Table 1 column (e). Assuming that the maximum replacement percentage is 61%, the quantity of concrete mentioned can thus be replaced by (14,500,000 * 0.61) / 1.9 = 4,650,000 m^3 of wood. The quantities mentioned are on an annual basis.

The wood crop from a Dutch forest amounts to approximately 5 m^3/ha/annually for coniferus wood, 3.5 m^3/ha/annually for hardwood (broad-leaved trees) and 7.3 m^3/ha/annually for softwood (broad-leaved trees), see Ministerie van Landbouw, Natuurbeheer en Visserij - Ministry of Agriculture, Nature Conservation and Fisheries -, 1992 p. 86. Once a forest is fully grown a secondary crop can reach an average of 9.0 m^3/ha/annually. Assuming that an average crop is 5 m^3/ha/annually, about 4,650,000 / 5 = 930,000 ha of forest will be needed, see Table 2 column (d). The quantity of building is considered to remain almost steady in the future.

Because it is difficult to predict the level of the building quantity for the distant future, scenarios have been drawn up should the building quantity halve and double, see Table 2 columns (b)/(c), (d)/(e) and (f)/(g). It appears that there is a linear correlation between investments in the building industry an the use of concrete in The Netherlands [2]. On this basis it is assumed that the use of concrete fluctuates in the same way as the investment in the building quantity (investments). In addition to that a variation in the replacement percentages has been made. After all it remains to be seen if the maximum replacement level of 61% will ever be achieved. That is why replacement percentages of 10%, 35% and 61% have been used, see Tabel 2, column (a). Table 2 shows the required additional afforestation for the different replacement scenarios and building scenarios.

	Half the building quantity		Building quantity 1990-1995		Twice the building quantity	
Wood replacement scenario (a)	Required afforestation in ha (b)	Percentage of Dutch soil (c)	Required afforestation in ha (d)	Percentage of Dutch soil (e)	Required afforestation in ha (f)	Percentage of Dutch soil (g)
10%	80,000	(1.9%)	150,000	(3.7%)	310,000	(7.5%)
35%	270,000	(6.6%)	530,000	(13.1%)	1,070,000	(26.2%)
61%	470,000	(11.5%)	930,000	(22.8%)	1,860,000	(45.6%)

Source: Van Barneveld, e.a. 1997

Table 2. *The required amount of additional afforestation if 10%, 35% or 61% of concrete is replaced by wood. Between brackets: the hectares of forest expressed in percentages of the Dutch soil*

The total surface area of The Netherlands is about 4,100,000 hectares. About 2,400,000 hectares are used for agriculture, see CBS, 1995, p. 28. Of this area only 335,000 hectares are woodland, This means that only 8% of The Netherlands is forested. For the different scenarios Table 2 shows the percentages of Dutch soil which should be forested to provide wood for the replacement of concrete in the various cases. Compared to the agricultural area in The Netherlands, the calculated afforestation in Table 2 is very considerable.

7. Concluding observations

In Table 3 not only the required hectares for wood but also the required hectares for the extraction of sand and gravel are represented, see columns (c), (e) and (g) of Table 3. The variation in these surfaces is again a result of possible variations in thickness of the layers of sand and gravel under the surface.

It should be emphasized that in this article only cement concrete has been considered. If cement concrete is replaced by wood then in principle, the use of sand-lime bricks and bricks will also have to be looked at closely. The annual consumption of sand for sand-lime bricks in The Netherlands is about 5 million tonnes. These 5 million tonnes are relatively minor, compared to the 26 million tonnes of coarse sand and gravel, but nevertheless not to be ignored. For the coarse ceramic industry an annual 2.5 million m^3 of clay is extracted in The Netherlands. If these products would also be partially replaced by wood, the calculated hectares for forests in Tables 2 and 3 will increase. As for the calculation of hectares for sand and gravel extraction in Table 3, no changes due to the future use of secondary raw materials, alternative materials, a more economical way of building etc. have been taken into account. Through this, the amount of hectares to be excavated could be reduced considerably in the future. In Table 3 the amount of hectares for wood are considered for a period of over 75 years. Within such a space of time big changes may take place.

	Half the building quantity		Building quantity 1990-1995		Twice the building quantity	
Wood replacement scenario (a)	Required afforestation in ha (b)	Required ha for concrete in ha/year (c)	Required afforestation in ha (d)	Required ha for concrete in ha/year (e)	Required afforestation in ha (f)	Required ha for concrete in ha/year (g)
00%	000,000	55-108	000,000	110-215	000,000	220-430
10%	080,000	50-97	150,000	99-194	310,000	198-388
35%	270,000	36-70	530,000	72-140	1,070,000	144-280
61%	470,000	22-42	930,000	43-84	1,860,000	86-168

Source: Van Barneveld, e.a. 1997

Table 3 *The required additional hectares of wood if 10%, 35% and 61% of the cement concrete is replaced by wood and the required hectares for the quarrying of sand and gravel for concrete without considering the replacement by alternative and secondary materials*

In the Dutch Structural Outline Plan on Surface Minerals, volume four, it is assumed that for the years 2000 - 2011, 1.4 million tonnes of (coarse) sand - which is 5.5% of the consumption of coarse sand - and 4.5 million tonnes of gravel - which is 18.4% of the consumption of gravel - will be replaced by secondary raw materials (see Ministerie van Verkeer en Waterstaat, 1996, p. 12). In view of this the amount of hectares to be excavated, as mentioned in Table 3, will almost certainly be reduced in the far future. If The Netherlands is going to use e.g. crushed stone exclusively in concrete instead of the coarser fractions, the calculations regarding the substitution of wood for concrete will in principle remain valid as far as the hectares of afforestation mentioned in Table 3 are concerned. The amount of hectares for wood in Table 3 will reduce if the environmental standard of concrete that is made up of secondary materials works out much better than the environmental standard for a construction in wood.

Suppose we will continue building with concrete on the same scale we knew from the years 1990-1995 for the next 100 years. And suppose that sand and gravel will be quarried along the rivers in The Netherlands and the surrounding countries. To achieve this it is estimated that 11,000 - 21,500 hectares will be required, without considering the application of alternative and secondary materials. These hectares pale into insignificance compared to the amount of hectares that will have to be afforested, see Table 3. As far as the hectares go, those required for building with concrete compare favourably with those required for building with wood. The figures will become even more favourable if the application of secondary and alternative materials are taken into account.

In comparison with our surrounding countries the Netherlands is the most densely populated country in Europe, 364 inhabitants per square km. Consequently the soil is scarce and relatively expensive. If the higher wood-replacement percentages - till 61% - are considered, the Netherlands will never be self-sufficient in the distant future. This means that wood would have to be imported. On top of that, under the current economic circumstances the planning of new productive forests will only be possible thanks to subsidies. Subsidizing wood and imposing levies on surface minerals may change the picture drastically in the future. Nevertheless it does not seem likely that half (!) the agricultural area in The Netherlands will be afforested.

The countries that surround us are relatively much more wooded. Germany and France e.g. have 10,500,000 and 14,850,000 hectares of wood respectively, see CBS, 1995, p. 28. This means 0.13 ha/inhabitant and 0.25 ha/inhabitant respectively, see CBS, 1995, p. 28). In The Netherlands this index number is only 0.02 ha/inhabitant, see Stichting Bos en Hout, 1995. This is by the way comparable with the quantity of wood per inhabitant in the U.K. (0.04 ha/inhabitant). If The Netherlands were to become self-sufficient, the index number would have to rise to 0.08 ha/inhabitant (the existing 335,000 ha + an additional 930,000 ha) / 15,500,000 inhabitants = 0.08 ha/inhabitant).

Possible future shifts in the consumption of building materials are likely to occur on an international scale. If our country is going to use more wood in the building industry it will probably happen in our neighbouring countries too. This would mean that countries such as France, Germany and the U.K. are not not very likely to become our suppliers since they need the wood themselves. Probably the wood we need will have to be imported from wooded areas such as e.g. Scandinavia. Countries with relatively few inhabitants and relatively much wood will be the most likely candidates. The Scandinavian countries - Norway, Sweden and Finland - have about 60,000,000 ha of forests to 18 million inhabitants, which is 3.35 ha/inhabitant! In view of the fact that the other European countries have far less wood at their disposal, it seems desirable to investigate whether Europe may ever be self-sufficient, if the European building industry would undividedly change over to building with wood.

It looks as if a process is going on in Europe on an international scale, where-by more and more aggregates from thinly-populated areas are exported to densely-populated areas. As for wood such a process already started a long time ago. In that respect the production of timber does not differ from the extraction of aggregates.

If in the future gravel and possibly even coarse sand are going to be replaced by crushed rock, this will - measured in hectares - have a favourable effect on the use of space. Recently new crush-techniques have also been developed, as a result of which the crushing of rocks would require 50% less energy (see Cobouw, 18-03-1997). Due to these developments the use of crushed stone in concrete is likely to work out favourably compared to the use of wood. The development of new techniques will result in readjusting environmental measures of the building materials concerned over and over again. That is why it is very difficult to predict which building material will be given preference to in the distant future.

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Notes

[1] The assumption is that 1 m^3 of wood replaces 2 m^3 of concrete.

[2] Concrete consumption from 1986-1994 (1,000 m^3):
12,500 - 12,200 - 14,200 - 14,400 - 14,670 - 14,511 - 14,453 - 13,660 - 15,516 * 1,000 m^3.
Investments from 1986-1994 (million Dutch Guilders, in prices 1990):
49,630 - 50,600 - 55,530 - 56,760 - 56,810 - 58,030 - 56,020 - 57,050 million Guilder.
The linear regression model is as follows:
Concrete = 0.2537 * Investm. R = 0.88; Durbin-Watson = 1.9; T.stat. = 84.9; 2-tail sig. = 0.0000.